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**POWER CONTROL CIRCUIT WITH ACTIVE IMPEDANCE  
TO PREVENT SENSING OF SPURIOUS INFORMATION**

**BACKGROUND OF THE INVENTION**

**1. Field of the Invention:**

5                   The present invention relates to a power control circuit with sensing circuitry to sense information about a power device and with active impedance circuitry to prevent sensing of spurious information. More particularly, the invention can be implemented in a noise immune power control circuit to eliminate spurious measurements due to high voltage surge and other causes.

10                   **2. Description of the Related Art:**

                  Circuits for driving electrical devices such as motors typically include power devices such as power field effect transistors (FETs) across which output power is provided. The power FETs can, for example, be insulated gate bipolar transistors (IGBTs).

15                   Circuit 10 in Fig. 1, for example, is a conventional motor controller circuit with low side power FET 12 and high side power FET 14 illustratively connected with diodes 16 and 18 in a half bridge between a DC bus supplying 1200 volts and a common ground. Circuit 10 includes integrated circuit (IC) 20, a representative power IC for this and similar applications. On the low side, IC 20  
20 includes driver 22, comparator 24, and buffer 26, and on the high side, driver 30, comparator 32, and buffer 34.

                  IC 20 has output pins for controlling power FETs 12 and 14 and also input pins for receiving information about operation of FETs 12 and 14.

In circuit 10, output pins LO and HO serve respectively as gate control pins for FETs 12 and 14. The central node of the half bridge is connected to pin VS, and provides voltage potential to the output device, in this case a motor.

5 Low side desat/voltage feedback (DSL/VFL) input pin serves to receive information about operation of FET 12, while high side desat/voltage feedback (DSH/VFH) input pin serves to receive information about operation of FET 14. The DSL/VFL and DSH/VFH pins provide desat input indicating a short circuit condition across a power FET, in response to which circuit 10 switches into a soft shutdown mode. The DSL/VFL and DSH/VFH pins also provide voltage feedback  
10 input indicating voltage across a power FET, in response to which a microprocessor controller for circuit 10 can manage power output to increase system efficiency. The DSL/VFL and DSH/VFH pins are examples of sensing nodes for connecting to power devices like FETs 12 and 14.

15 Information detected through desat and voltage feedback inputs of IC 20 can be understood from circuit 40 in Fig. 2, whose components represent either low or high side components of circuit 10, as suggested by the pin labels. In Fig. 2, components on IC 20 are shown at left, while components on a board on which IC 20 is mounted are shown at right.

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20 In circuit 40, power FET 42, for example, represents either FET 12 or FET 14, with its gate connected either to the LO or the HO pin, which in turn receives gate control voltage from driver 44, representing either driver 22 or driver 30 on IC 20. Similarly, comparator 46 represents either comparator 24 or comparator 32, and buffer 48 represents either buffer 26 or buffer 34. Comparator 46 serves as  
25 part of sensing circuitry, providing a sense result signal in response to a sense input signal that includes information received at the DS/VF pin. The sense result signal at the output of comparator 46 includes information derived from the sense input signal about operation of FET 42

The DS/VF pin is connected to a power supply, either  $V_{CC}$  or output pin VB, through resistance 50, representing resistance 52 or resistance 54 in circuit 10. Resistance 50, which could for example be 100 Kohms, provides a sufficiently high impedance to reduce current.

5 Pin DS/VF senses the source to drain voltage across FET 42 through high voltage diode 60, representing diode 62 or diode 64 in circuit 10. Under normal conditions, diode 60 is forward biased and turns on when FET 42 is on; then, when FET 42 turns off, diode 60 becomes reverse biased and also turns off; then, when FET turns on again, diode 60 again becomes forward biased and turns on.

10 One function of diode 60 is to allow detection of a short circuit condition in which voltage across FET 42 is high even though FET 42 is gated on. When a short circuit condition occurs while FET 42 is on, damage to FET 42 must be prevented by turning it off through its gate signal. The short circuit condition causes the voltage at node 66 to rise, and diode 60 becomes reverse biased and turns off,  
15 indicating detection of the short circuit condition. As a result, current begins to flow through the path from  $V_{CC}$  or VB through resistances 50, 70, and 72 to ground, in which resistances 70 and 72 are illustratively at 200 Kohms and 500 Kohms, respectively. The voltage at the DS/VF pin rises, and the voltage to the "+" input of comparator 46 also rises relative to the "-" pin. As a result, the output from  
20 comparator 46 goes high, indicating the short circuit condition turning off driver 44, which then turns off FET 42 through the gate signal.

One problem with the circuitry in Figs. 1 and 2, referred to herein as "the interference problem", relates to high frequency noise from the DC bus. As shown in dashed lines, diode 60 behaves like capacitance 74 when it is off, allowing  
25 high frequency noise to reach comparator 46. For example, capacitance 74 can pass both negative and positive spikes, as shown by the waveforms in circle 76. A

negative spike can pull down the voltage at the "+" input of comparator 46, falsely indicating a short circuit condition.

Another problem, referred to herein as "the sensing problem", relates to voltage feedback (VFB) information received through the DS/VF pin. To increase system efficiency, accurately timed VFB information indicating when FET 42 turns on and off should be provided to the controller, allowing it to make appropriate adjustments. In circuit 40, VFB information can be obtained using the same circuitry that detects short circuit conditions, by comparing the DS/VF pin voltage to a threshold or reference voltage received at the "-" input of comparator 46 from voltage source 80, representing either voltage source 82 or voltage source 84 on IC 20, which could be implemented, for example, with a zener diode or other appropriate device. Comparator 46 in turn provides a signal with VFB information to a microprocessor controller through buffer 48 and the VFL or VFH output pin.

When FET 42 is turned off, the DS/VF pin is at a high voltage relative to the threshold and comparator 46 provides a high output to buffer 48. Similarly, when FET 42 is turned on, the DS/VF pin is at a low voltage relative to the threshold and comparator 46 provides a low output to buffer 48.

The sensing problem arises because spurious signals can be provided while FET 42 makes a transition from off to on, as illustrated in Fig. 3. The upper waveform in Fig. 3 shows the voltage across FET 42, the middle waveform the voltage at the DS/VF pin relative to ground, and the lower waveform the VFB signal provided by comparator 46 through buffer 48 to the VFL or VFH pin.

From  $t_0$  to  $t_1$ , FET 42 is turned off and the voltage across it has a high value of several hundred volts, as illustrated by segment 100 of the upper waveform. As a result, diode 60 is off, so that the voltage at the DS/VF pin is also high relative to ground, as illustrated by segment 102, and comparator 46 provides a high signal

indicating that its "+" input is at a higher voltage than its "-" input, as illustrated by segment 104.

At t1, driver 44 begins to provide a high gate signal to FET 42 to turn it on. As a result, the voltage across FET 42 makes a rapid transition downward of several hundred volts in a few hundred nanoseconds, illustratively shown by segment 110.

During the off-to-on transition of FET 42, diode 60 remains temporarily off and therefore acts as a capacitor, so that a high frequency negative spike that passes through to the DS/VF pin, illustrated by segment 112, can cause comparator 46 to change state, illustrated by transition 114 at t2. This change of state does not accurately indicate a time at which the voltage across FET 42 crosses a threshold voltage VTH, however, because the voltage across FET 42 still exceeds the VTH.

During an on-to-off transition of FET 42, illustrated by the waveform segments between times t6, t7, and t8, diode 60 is on and the change of state of comparator 46 at t7 is accurately timed.

A central cause of the sensing problem is diode capacitance coupling during an off-to-on transition, leading to inaccurate VFB signal timing. As a result of coupling across diode 60, negative spikes and other spurious voltage variations can reach the DS/VF pin as a result of inaccurately timed state changes by comparator 46. In addition, changes in the sizes of FET 42 and diode 60 as well as changes in the board and in the slope of segment 110 can affect VFB signal timing, contributing to VFB inaccuracies.

#### SUMMARY OF THE INVENTION

The present invention provides a new power control circuit that includes correction circuitry that prevents spurious information in a sense input

signal. As a result, the correction circuitry alleviates the interference and sensing problems described above.

5                    Like the circuits described above, the new circuit includes sensing circuitry, which can include a comparator as described above or other appropriate components to provide a sense result signal in response to a sense input signal: The sense input signal includes information received through a gating device, such as a diode or other appropriate device connected between the sensing circuitry and a power device; the sense result signal in turn includes information derived from the sense input signal about operation of the power device.

10                   In addition, the circuit of the present invention includes correction circuitry that prevents the sense input signal from including spurious information received from the gating device. This elegant technique alleviates the interference and sensing problems described above and can be implemented with relatively simple circuitry.

15                   Spurious information from the gating device can take the form of negative spikes, as described above. The correction circuitry can accordingly prevent negative spikes in the sense input signal. If the gating device is a diode and the power device is a FET, the correction circuitry can prevent negative spikes except when the FET is on.

20                   The correction circuitry can, for example, include a switchable or "active" impedance that can be turned on to prevent spurious information. For example, the switchable impedance can be turned on when the power device is turned off and, conversely, turned off when the power device is turned on.

25                   Where the sensing circuitry includes a comparator, as described above, the correction circuitry can receive the sense result signal from the comparator's output. The correction circuitry can prevent negative spikes when the

sense result signal indicates that the sense input signal is greater than a reference signal, indicating that the power device is off.

The circuit of the present invention can be embodied in an integrated circuit that includes sensing circuitry and correction circuitry. As described above, the integrated circuit can have a sensing node for connecting to the FET or other power device through the diode or other gating device. The switchable impedance can be connected between a power supply and the sensing node. Where the integrated circuit include components such that the sense input signal drops below a reference voltage if the gating device turns off, including a resistance between the power supply and the sensing node, the switchable impedance can be parallel to this resistance. The correction circuitry can also include switching circuitry for switching the impedance on and off in response to a signal indicating whether the power device is on or off, with the switchable impedance being turned on except when the power device is on. The signal indicating the device's state can be provided by a comparator in the correction circuitry, or it can be received from the sensing circuitry.

Other features and advantages of the present invention will become apparent from the following description of the invention which refers to the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic circuit diagram showing a conventional integrated power control circuit driving a half bridge motor controller with high and low side power field effect transistors (FETs), each with a respective driver and circuitry for sensing power FET operation.

Fig. 2 is a schematic circuit diagram showing in greater detail some components of the high or low side of the conventional circuit in Fig. 1 for sensing

short circuit and voltage feedback through a desat/voltage feedback (DS/VF) input pin.

Fig. 3 is a timing diagram showing the relation between three voltages in the circuit of Figs. 1 and 2—across a power FET, at the respective DS/VF pin, and at the respective voltage feedback output pin—to illustrate inaccuracies in voltage feedback sensing.

Fig. 4 is a schematic circuit diagram of a power control circuit with a switchable impedance between a power supply and a DS/VF pin.

Fig. 5 is a schematic circuit diagram of another power control circuit showing an implementation of a switchable impedance between a power supply and a DS/VF pin.

Fig. 6 is a timing diagram showing the relation between three voltages as in Fig. 3 for circuits like those in Figs. 4 and 5, illustrating accurate voltage feedback sensing.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

In Fig. 4, circuit 150 includes components on IC 152 and on board 154 on which IC 152 may be mounted. Components equivalent to components in Fig. 2 are labeled with the same reference numerals and can be understood from the above description.

Circuit 150 includes active bias circuitry 160 on IC 152. Circuitry 160 functions as correction circuitry to prevent the upper input signal to comparator 46 from including spurious information received from diode 60. By preventing spurious information, circuitry 160 alleviates the interference and sensing problems described above. Various other types of correction circuitry could be used in power control circuits with similar or different types of sensing circuitry.

Circuitry 160 includes switchable impedance element 162, an FET, connected between a power supply and the DS/VF pin to provide an active impedance at the pin. Impedance element 162 is parallel to resistance 50, shown in Fig. 4 as on IC 152 but which could instead be on the board on which IC 152 is mounted, as in Figs. 1 and 2. Impedance element 162 can be switched to prevent a negative spike from reaching comparator 46 without unnecessary increase in current. In contrast, merely reducing resistance 50 would reduce the effect of a negative spike, but would increase current.

Element 162 is illustratively switched by output from comparator 164, with its "+" input connected to receive the voltage at the DS/VF pin and its "-" input connected to receive an appropriate reference voltage from voltage source 166, which is shown as a battery but could be implemented with a zener diode or other appropriate device. When the output from comparator 164 is low, element 162 is turned off, but when comparator output is high, element 162 is turned on.

When FET 42 is on and voltage at DS/VF is low, amplifier 164 provides a low output, turning off element 162. In this case, no active impedance is provided, and the DS/VF pin sees the high impedance input of comparator 46 and a low impedance through diode 60 and FET 42, both of which are turned on. As a result, any spikes will follow the low impedance path through FET 42 to ground.

But when FET 42 is off and voltage at DS/VF is higher than the reference voltage from source 166, comparator 164 provides a high output, turning on element 162 to provide an active impedance at the DS/VF pin. In this case, the DS/VF pin sees a sufficiently low impedance through element 162 to sink a high frequency negative spike received as a result of capacitive coupling across diode 60. This solution therefore alleviates the interference problem.

In Fig. 5, circuit 180 similarly includes components on IC 182 and on board 184 on which IC 182 may be mounted. Components equivalent to components

in Figs. 2 and 4 are labeled with the same reference numerals and can be understood from the above description.

Circuit 180 includes active bias circuitry 190, a more specific implementation of active bias circuitry 160 in Fig. 4. Therefore, circuitry 190  
5 similarly functions as correction circuitry, preventing spurious information and alleviating the interference and sensing problems described above.

Circuitry 190 includes transistor 192, which can be an enhancement mode device that is turned on by a negative gate voltage or any other appropriate switchable impedance device. Like element 162 in Fig. 4, the channel of transistor  
10 192 is connected between a power supply and the DS/VF pin to provide an active impedance at the pin in parallel with resistance 50. When on, transistor 192 can sink any high frequency negative spikes received as a result of capacitive coupling across diode 60, preventing a negative spike from reaching comparator 46 and alleviating the interference problem.

Output from comparator 46 is provided to the gate of transistor 192  
15 through inverter 194, because transistor 192 is turned on by a negative voltage. When the output from comparator 46 is low, transistor 192 is turned off, but when comparator output is high, transistor 192 is turned on. As discussed above, output from comparator 46 is high when FET 42 is off, and the active impedance provided  
20 when transistor 192 is on therefore prevents negative spikes from reaching comparator 46 at such times. In this implementation, comparator 46, in addition to its sensing function, performs the function performed by comparator 164 in Fig. 4, providing a signal indicating the state of FET 42.

Fig. 6 illustrates how the techniques in Figs. 4 and 5 alleviate the  
25 sensing problem, which shows counterpart waveforms to those in Fig.3.

From  $t_0'$  to  $t_1'$ , FET 42 is turned off and the voltage across it has a high value of several hundred volts, as illustrated by segment 200 of the upper

waveform. As a result, diode 60 is off, so that the voltage at the DS/VF pin is also high relative to ground, as illustrated by segment 202, and comparator 46 provides a high signal indicating that its "+" input is at a higher voltage than its "-" input, as illustrated by segment 204.

5                   At t1', driver 44 begins to provide a high gate signal to FET 42 to turn it on. As a result, the voltage across FET 42 makes a rapid transition downward from several hundred volts to a few hundred millivolts, illustratively shown by segment 210.

10                   During the off-to-on transition of FET 42, diode 60 remains temporarily off and therefore acts as a capacitor, so that a high frequency negative spike could pass through to the DS/VF pin. But segment 202 continues at the same voltage an active impedance, provided either by element 162 in Fig. 4 or transistor 192 in Fig. 5, holds the voltage at the DS/VF pin and sinks high frequency spikes. As a result, the active impedance prevents the spikes from reaching the "+" input of  
15                   comparator 46, and segment 204 continues at the same voltage because the output from comparator 46 is unchanged.

20                   At time t5', however, the voltage across FET 42 crosses below the threshold voltage VTH at which diode 60 switches on. As a result, voltage at the DS/VF pin makes a rapid transition downward, illustrated by segment 212, causing a low sense input signal at the "+" input of comparator 46. Comparator 46 immediately changes state to provide a low output, illustrated by transition 214 immediately after t5'. Unlike transition 114 in Fig. 3, this change of state accurately indicates a time at which the voltage across FET 42 crosses VTH.

25                   During an on-to-off transition of FET 42, illustrated by the waveform segments between times t6', t7', and t8', diode 60 is on and the change of state of comparator 46 at t7' is accurately timed, as in Fig. 3.

Therefore, the techniques in Figs. 4 and 5 alleviate both the interference and sensing problems.

Although the present invention has been described in relation to particular embodiments thereof, many other variations and modifications and other  
5 uses will become apparent to those skilled in the art. It is preferred, therefore, that the present invention be limited not by the specific disclosure herein, but only by the appended claims.

FOI 007 - 15093660